United States Patent

Bruinsma

[15] **3,695,078**

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[54] **METHOD AND APPARATUS FOR ROLL-FORMING OR ROLL-FINISHING GEAR PIECES**

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[21] Appl. No.: **89,916**

[52] **U.S. Cl.** **72/101,** 29/159.2, 72/102

[51] **Int. Cl.** **B21h 5/04**

[58] **Field of Search**....72/80, 84, 101, 102, 105, 108, 72/109; 29/90 B, 159.2

[56] **References Cited**

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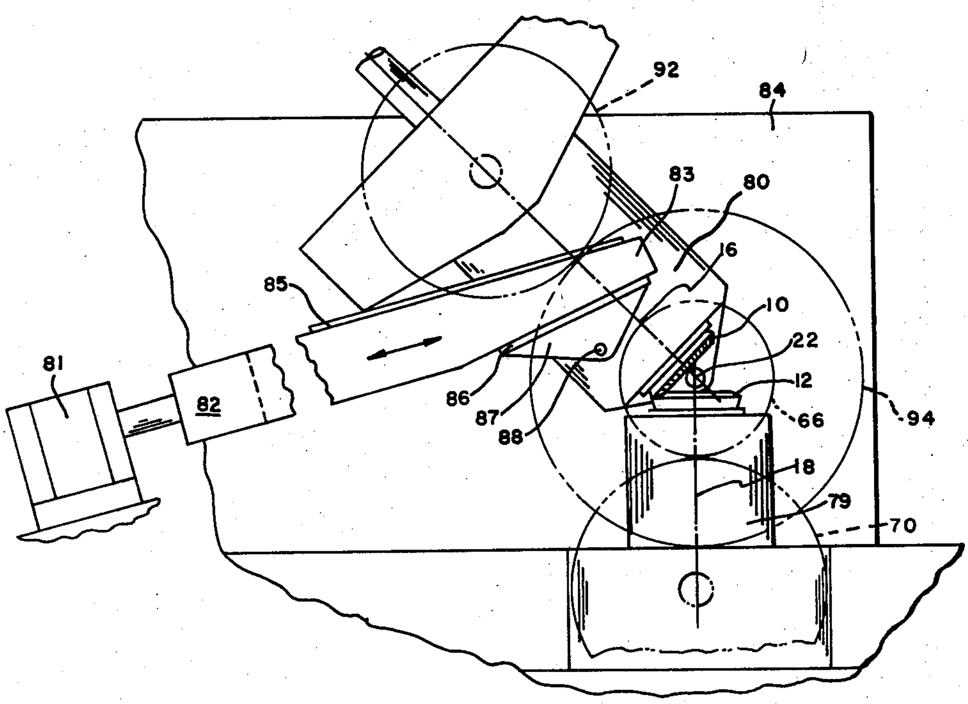
Primary Examiner—Lowell A. Larson
Attorney—Morton A. Polster

[57] **ABSTRACT**

A method for forming or finishing gear tooth configurations on a workpiece provides for a rolling together of a die member and a workpiece with a feed motion which essentially pivots about and axis substantially coincident with a common normal to the center axes of rotation of both the die member and the workpiece. The pivotal feed motion is continued so as to progressively engage the die member and the workpiece with each other to a desired limit depth which forms gear tooth configurations on the workpiece.

A machine for rolling together a die member and a workpiece to form a gear tooth configurations on the workpiece, including means for mounting and rotating the die member relative to the workpiece so that there is provided a pivotal feed motion about an axis substantially coincident with a common normal to the center axes of both the die member and the workpiece.

19 Claims, 15 Drawing Figures



PRIOR METHOD

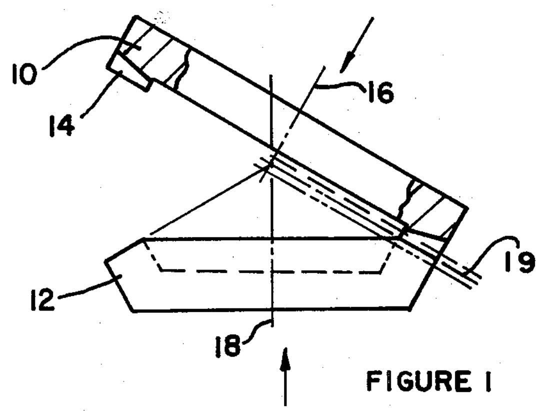


FIGURE 1

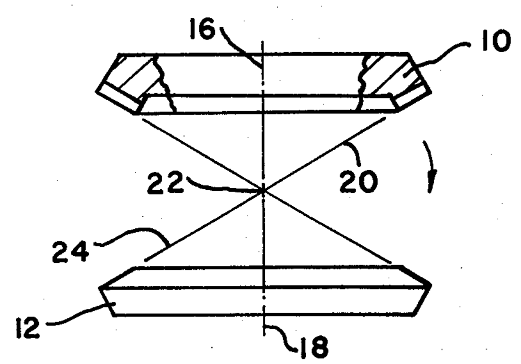


FIGURE 2

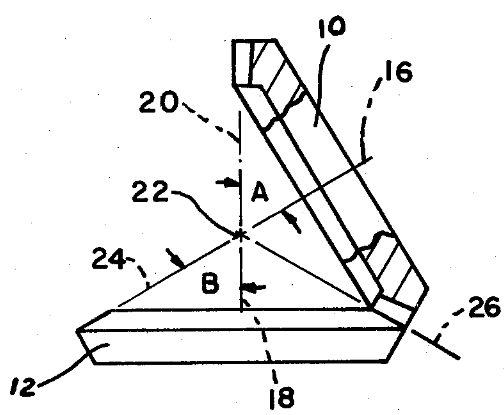


FIGURE 3

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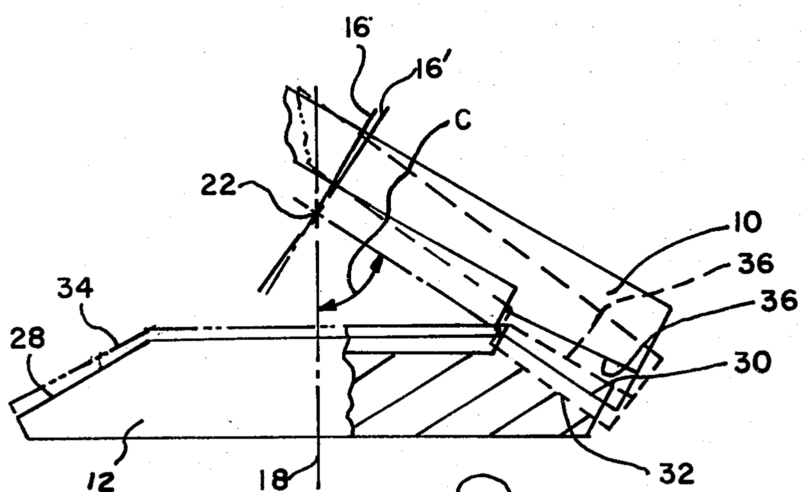

FIG. 4

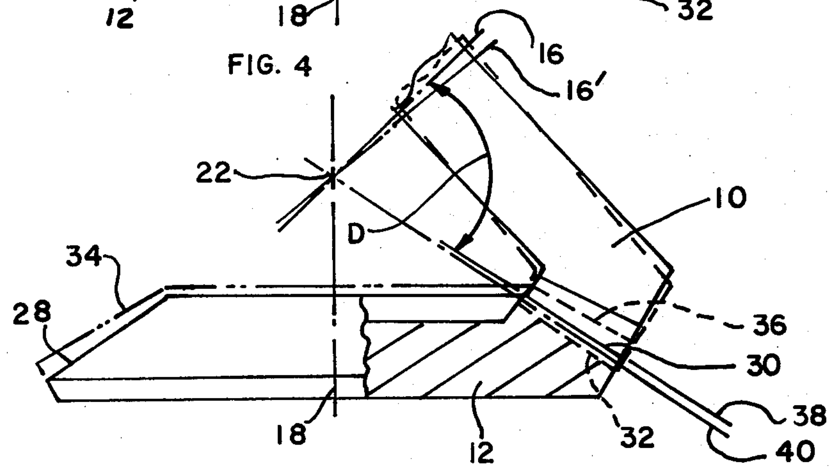

FIG. 5

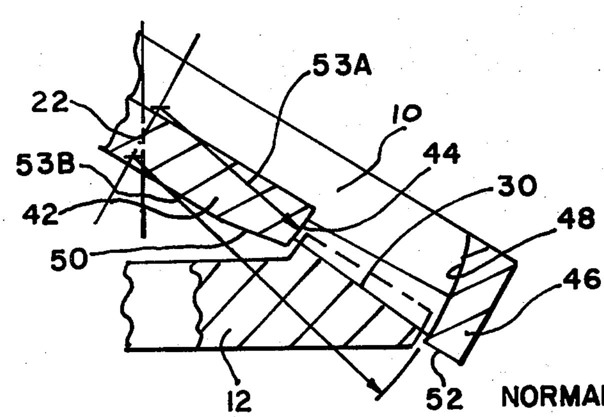

FIG. 6

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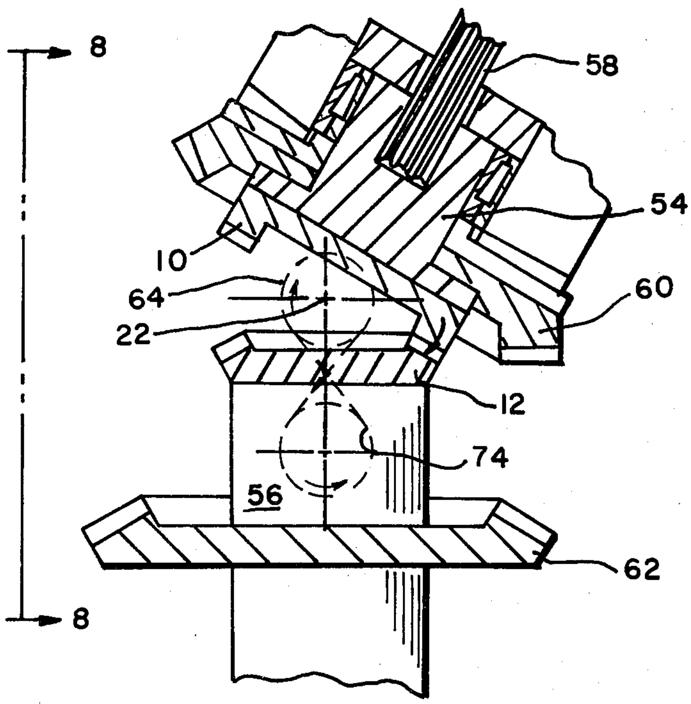

FIGURE 7

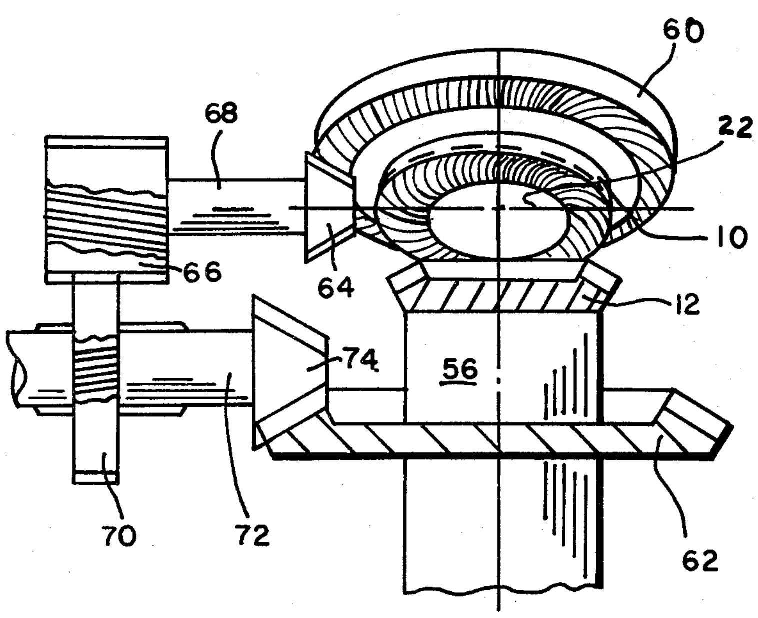

FIGURE 8

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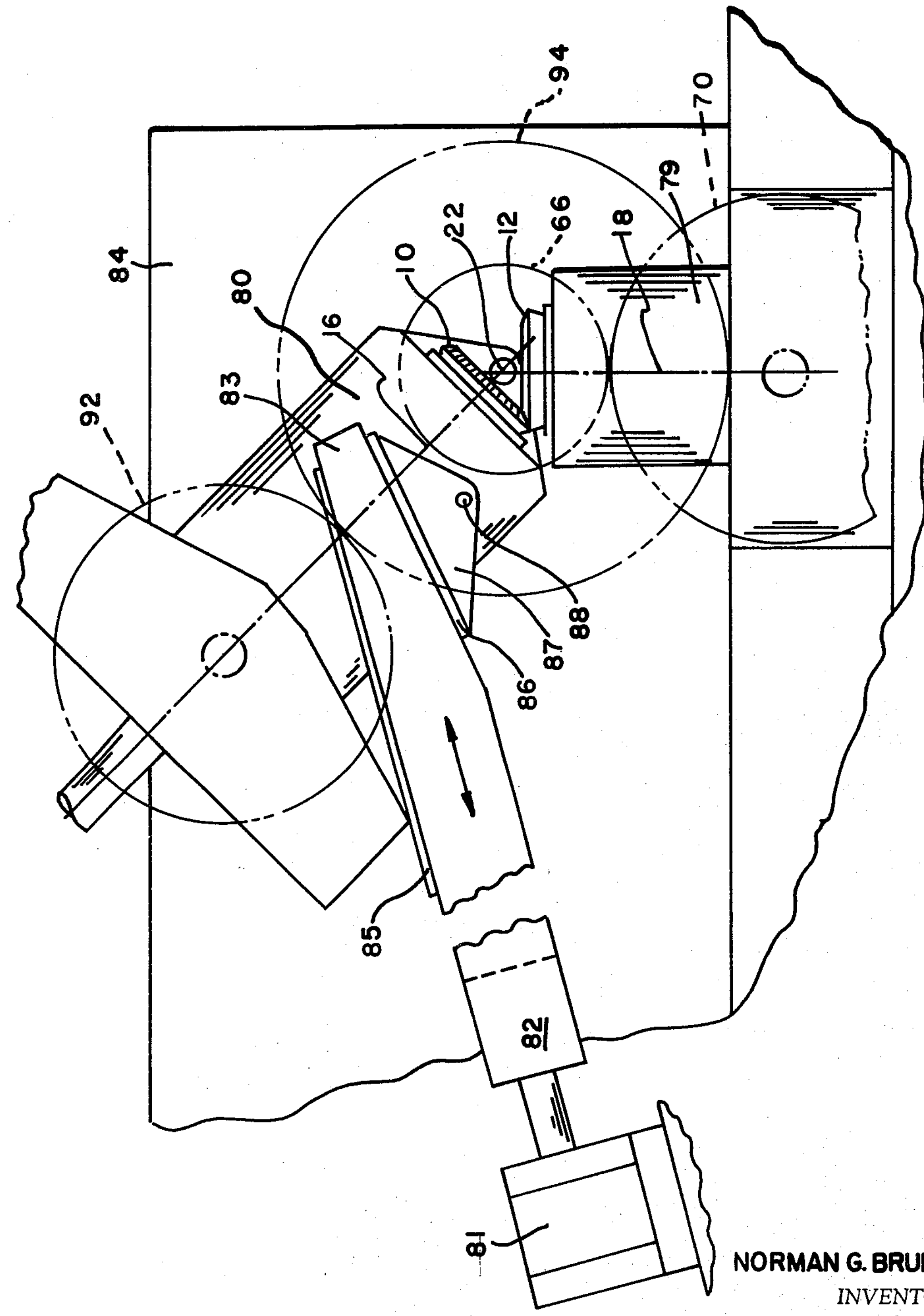

FIGURE 9

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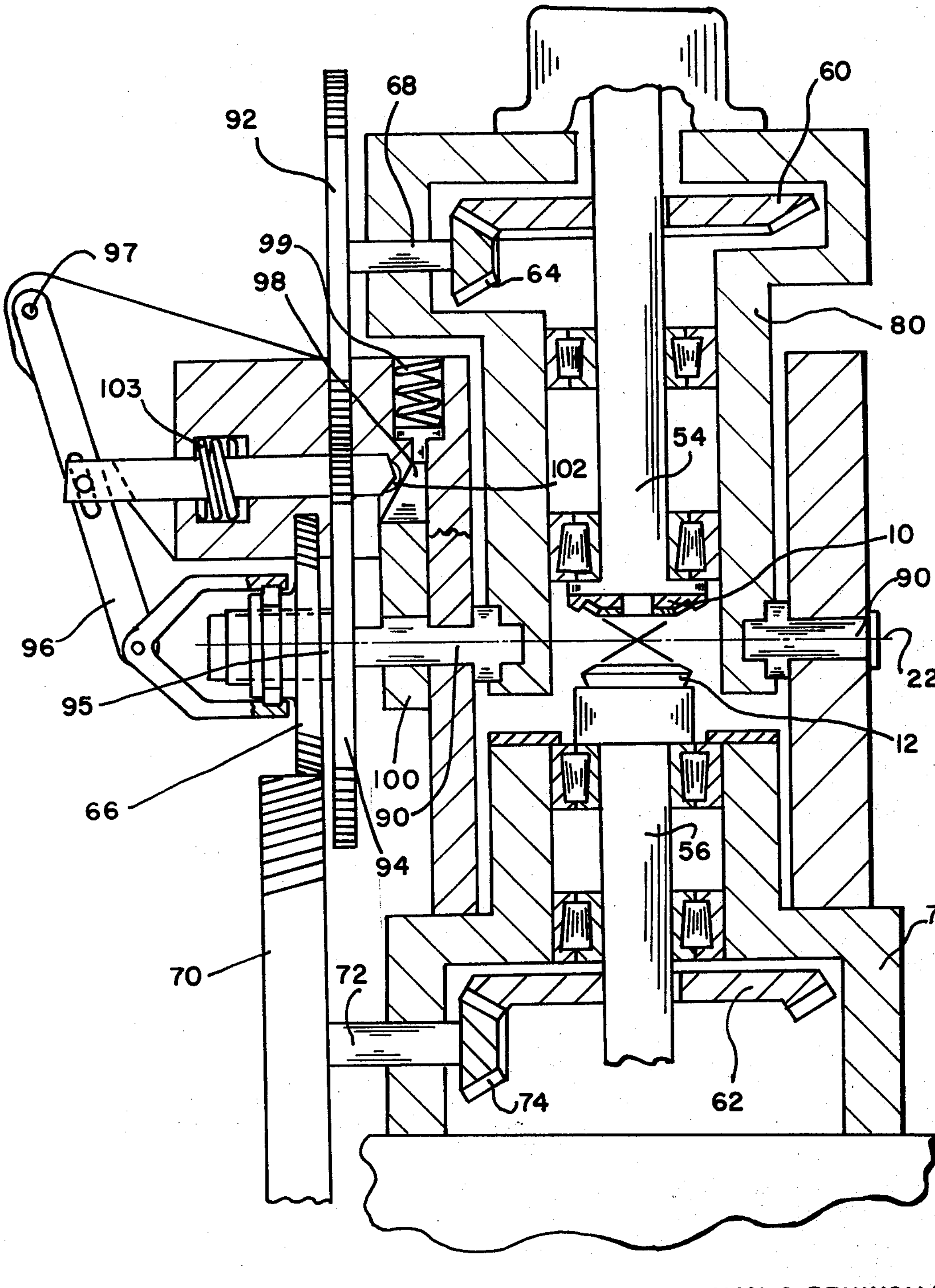

FIGURE 10

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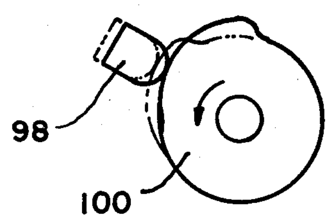

FIGURE 11

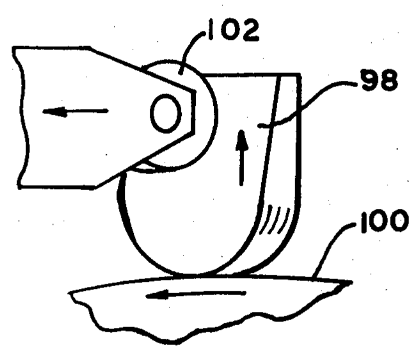

FIGURE 12

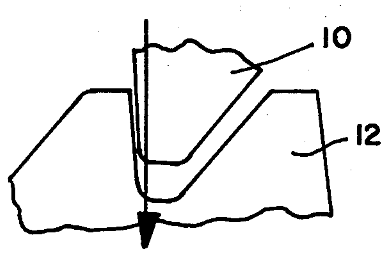

FIGURE 13

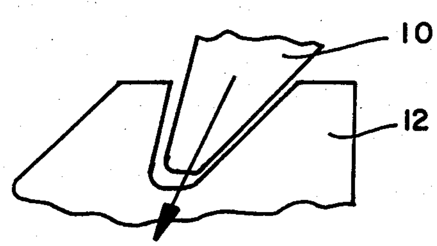

FIGURE 15

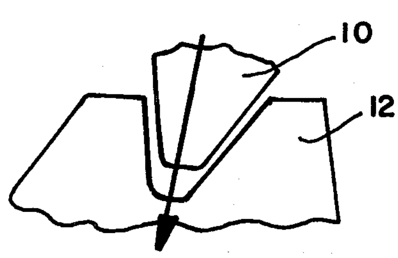

FIGURE 14

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METHOD AND APPARATUS FOR ROLL-FORMING OR ROLL-FINISHING GEAR PIECES

BACKGROUND AND BRIEF DESCRIPTION OF INVENTION

The present invention relates to a method and apparatus for roll-forming of workpieces, being especially useful for rolling generated tooth configurations in geartype elements, particularly in tapered gear members, such as straight bevel, spiral bevel, and hypoid gears.

In the context of this specification and its claims, reference will be made to the use of a die member for forming or finishing gear teeth on a workpiece. These terms are intended to describe a tool, or other member which may be considered a die member in this art, and a work blank, or its equivalent, upon which gear tooth profiles can be formed by a displacement of metal, or other material, from which the workpiece is fashioned. The die member is formed from a material which is not displaced or changed in its configuration during the roll-forming or finishing of tooth shapes on the workpiece. The workpiece may be in the form of a blank having no initial tooth profile formations at all, or it may have partially formed tooth profiles prior to further roll shaping in accordance with this invention. Other terminology which describes specific relationships and motions between working members, as used in this specification, will be defined in detailed descriptions later or with reference to drawings illustrating various features of the invention.

It is known in this art to form gear configurations by displacing metal in a workpiece with a die member which is brought into engagement with the workpiece and which is rotated, or rolled, with the workpiece. It has been a known practice to roll-form or roll-finish gears by providing for a relative axial displacement of a die member and a workpiece along one or both of their center axes of rotation. In accordance with known roll-generating theory it has been considered necessary, or at least preferably ideal, to provide for a feed motion, between a die member and a workpiece, which is perpendicular to the instantaneous axis of rotation of the die member and the workpiece. (As used herein, "the instantaneous axis of rotation" is the common pitch cone element at any given instant, of the pitch cones of two rolling members.) Axial feed of at least the die member has been utilized for this purpose and, when tapered die members have been used, axial feeds of both the die member and the gear member have been required. As a result of this practice and the theory upon which it is based, prior art efforts have concentrated on providing for relatively complex and costly methods and apparatus for axially displacing both a die member and a workpiece, at controlled rates, along their respective axes during roll-forming or roll-finishing operations for tapered gears.

It can be appreciated that tremendous forces and pressures are involved in roll-forming and roll-finishing operations, especially when the workpiece is in a cold and unplasticized state at the beginning of the operation. Whatever apparatus is used in a gear rolling method requires a complete machine structure, including bearings and couplings, that can withstand the extreme forces required for forming desired tooth configurations in a workpiece. Axial feed systems which

have been tried in the past for tapered gear manufacture have necessarily required relatively complex machinery to effect controlled rates of axial displacement of both a die member and a workpiece, and certain spline couplings and bearings of such apparatus have been heavily loaded and have presented problems with respect to designing and building reliable machinery.

The present invention departs from prior art practices by eliminating any necessary requirement for axial feed of either a die member or a workpiece during a roll-forming or roll-finishing operation. Although relative axial displacement can be eliminated in the practice of the present invention, the feed motion provided is still essentially perpendicular, at any given instant, to the instantaneous axis of rotation of the die member and workpiece being brought together into rolling engagement. This feed motion is accomplished by pivoting the die member and the workpiece, relative to each other, about an axis which is substantially coincident with a common normal to the center axes of both the die member and the workpiece. It should be appreciated that such center axes do not necessarily have to interest, e.g. as may be true when rolling with die and workpiece in a hypoid relationship, but where the center axes of the die member and the workpiece do intersect one another, their common normal passes through the intersection of the two center axes. It should be particularly noted that the pivotal motion of this invention is not a mere provision for adjustment or setting of angular position of a die member relative to a workpiece but rather constitutes a feeding motion for maintaining particular relationships between a die member and a workpiece during roll formation or finishing of tooth profiles on the workpiece.

By departing from prior art practices of axially feeding one or both of a die member and a workpiece, substantial benefits are attained. Firstly, it has been found that the pivotal feed motion of the present invention appears to contribute to a more natural rolling engagement between a die member and a workpiece, and this reduces some of the load forces involved in cold rolling of gear profiles. Additionally, the particular feed motion involved in the present invention allows for a design and construction of machinery which, while relatively simple as compared to prior art structures, is rigid and strong for carrying out the cold rolling of precision gear profiles.

In using the novel feed motion and method of the present invention, gear geometry can be manipulated and controlled with relatively simple machinery. In fact, in the manufacture of specific forms of tapered gears, such as hypoid gears, the pivotal feed motion of the present invention provides for a relatively simple means of modifying the turning ratio between die member and workpiece in proportion to the feed rate, and this is important where an unbalanced pressure angle profile is desired in the finished gear piece. Further, the position of the instantaneous axis of rotation between a die member and a workpiece can be controlled by a choice of the pitch cone angle for the die member, and this offers desirable effects on tooth geometry and on material flow in the workpiece.

Apparatus for practicing the method of the present invention provides for first and second spindle means which carry a die member and a workpiece, respectively. The spindle means are positioned and mounted in such a way that one of the spindles can be pivotally moved about an axis substantially coincident with a common normal to the center axes of the die member and the workpiece so as to bring the die member into progressive engagement with the workpiece to a desired depth limit. Also, driving means are provided for rotating at least one of the spindles, and the die member or workpiece associated therewith, so that a rolling engagement is achieved between the die member and the workpiece during progressive engagement of the two.

The apparatus is relatively simple and strong with no heavily loaded splines for axial feeds. Further, a relatively short and lightly loaded gear train can be used, and loads on bearings are reduced. The pivotal feed motion of the apparatus provides for a natural modification of the normal turning ratio of tool and workpiece during infeed, and means are provided for controlling or compensating for this natural component of relative rotation to permit selective control of tooth geometry on the workpiece.

For the purpose of supplying background information on various and representative prior art methods and apparatus relating to the general subject of gear forming by rolling, reference is made to U.S. Pat. Nos. 1,240,914; 1,240,916; 1,240,917; 1,240,918; 1,617,445; 2,883,894; and 3,053,126.

These and other advantages and features of the present invention will become more apparent in the detailed discussion which follows, and in that discussion reference will be made to the accompanying drawings as briefly described below.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a schematic illustration depicting prior art practices for roll formation of gears;

FIG. 2 is a schematic illustration of geometric relationships involved in the method of the present invention;

FIG. 3 is an illustration of the die member and workpiece shown in FIG. 2 after experiencing a pivotal feed motion of the type contemplated by the present invention;

FIG. 4 is an enlarged schematic illustration showing steps of progressive, rolling engagement between a die member and a workpiece when the die member is in the form of a crown gear or near-crown gear;

FIG. 5 is an illustration similar to FIG. 4 to depict relationships when the die member is in the form of a tapering tool;

FIG. 6 is a schematic illustration of one form of shrouding means which may be utilized in combination with the die member or workpiece;

FIG. 7 is a schematic elevational view of a simple form of apparatus for carrying out the method of the present invention;

FIG. 8 is an enlarged schematic view taken on lines 8—8 of FIG. 7 for illustrating a particular driving means for a die member and a workpiece;

FIG. 9 is an elevational view, somewhat similar to FIG. 7 but from an opposite side of a machine, for illustrating means for applying pivotal movement to a die member relative to a workpiece;

FIG. 10 is an elevational view, partly in cross section, for illustrating a means for selectively controlling the relative rotational movement between the die and workpiece in timed relation with the pivotal infeed motion of the die member;

FIG. 11 is an enlarged schematic view of a cam and wedge means incorporated in the machine of FIG. 10;

FIG. 12 is an enlarged view of a follower means associated with the wedge means of FIG. 11;

FIG. 13 is an enlarged sectional view of feed motion relationships between a die member and a tooth profile being formed in a workpiece where both the die member and the workpiece are rotated during roll-forming engagement in a ratio according to their tooth numbers;

FIG. 14 is a view similar to FIG. 13, but illustrating the resulting helical-like feed motion relationship when there is a certain control of the rotational infeed which results from pivotal feed of the die member relative to a workpiece; and

FIG. 15 illustrates a further degree of infeed control from what is shown in FIG. 14, for producing a negative inclination on one side of a helical tooth profile.

DETAILED DESCRIPTION OF INVENTION

FIGS. 1 through 3 illustrate basic geometric relationships between die members and workpieces for showing a comparison of the method of the present invention with the methods of prior art techniques. As shown in FIG. 1, the prior art practice has been one of positioning a die member or tool 10 to engage and deform a workpiece 12 and to thereby impart tooth profile configurations into the material of the workpiece. Typically, the die member 10 is provided with shaped tooth configurations 14 which dictate profile configurations for tooth formations on the workpiece 12 when the die member and the workpiece are engaged and rolled about the respective axes 16 and 18 of the die member and the workpiece. The axes 16 and 18 may be considered center axes of rotation for the die member and the workpiece, respectively, and will be referred to as such in this specification. It can be appreciated that whatever the system is for bringing a die member and a workpiece into rolling engagement, there must be some means for advancing the tooth forming portion of the die member into the material of the workpiece to a desired depth limit. The prior art practice has been one of providing for a relative feed motion which brings the pitch cone surfaces of the die member and the workpiece together in a direction which is perpendicular to their instantaneous axis of rotation (line 19 in FIG. 1). This desired relative feed has been accomplished in prior art methods in one of two ways: Where the die member was in the form of a crown gear tool, the die member was fed axially into the workpiece along its axis of rotation 16, or, where a tapered gear die member was used, by axially feeding both the die member and the workpiece along their respective axes 16 and 18, as indicated by the arrows in FIG. 1. These prior art methods require relatively complex apparatus which must be made even more complex because of the tremendous forces involved in displacing metal in a cold workpiece by the advancing engagement of a die member therewith. A representative system for controlling two axial feeds is illustrated and discussed in U.S. Pat. No. 2,883,894.

In contrast to the feed motion just described, the present invention provides for a relative feed motion between a die member and a workpiece which is generally arcuate in its path of travel and which will be described herein as a pivotal feed motion. FIGS. 2 and 3 illustrate basic geometric relationships involved in the pivotal feed motion of the present invention. As shown, a die member **10**, which may be in the form of a tool having tapered gear teeth thereon, is positioned for engagement with a similarly tapered workpiece blank **12**, which is illustrated as having no initial tooth slots or profiles formed therein. The novel pivotal feed motion is in the direction of the arrow in FIG. 2, being about axis **22** (an imaginary line extending perpendicularly out of the plane of the drawings) which is substantially coincident with a normal to both center axes **16** and **18** of the die and the workpiece. The pitch cone apexes of a die and workpiece may share a common point as shown in FIG. 3, or they may be offset from each other along axis **22**, (e.g., as may be the case when rolling with hypoid relationship). Also, both apexes may in some cases be positioned slightly displaced from axis **22**. Therefore, it should be understood that the invention herein contemplates that the pivot axis, while being defined as "substantially coincident" with a common normal to the center axes of the die and workpiece, may be displaced slightly from that imaginary line before or during the relative pivotal movement. FIG. 3 illustrates the relative positioning of a die member **10** and a workpiece **12**, of the type shown in FIG. 2, at the instant when the two are brought into rolling engagement. The engagement illustrated in FIG. 3 is one of initial rolling contact between the die member and the workpiece along the instantaneous axis of rotation **26** defined between the two. As just explained above, the pivotal feed motion of the present invention comprises a relative movement between the die member and the workpiece substantially about axis **22**, which is substantially coincident with the common normal to the axes **16** and **18** of both the die member and the workpiece. This may be accomplished by pivoting the die member alone about axis **22**, by pivoting the workpiece alone about axis **22**, or by pivoting both members about the axis with controlled rates of movement. In any event, it can be seen that the basic feed motion is generally arcuate in its path of movement, and the path is generally defined as being about a specific axis location. Another way of expressing this feed motion is to define it with reference to the instantaneous axis of rotation (i.e., to the pitch cone elements common to both die and workpiece at any given instant of progressive movement of the die member into the workpiece). It can be seen that the feed motion of the invention herein is one which is essentially perpendicular, at any given instant, to the instantaneous axis of rotation of the die member and the workpiece, and this feed motion is accomplished without axial feed of either the die member or the workpiece.

FIG. 3 also shows instantaneous pitch cone angles A and B, respectively, for both the die member **10** and the workpiece **12**, for purposes of defining pitch cone angle in later usage herein.

Thus, it can be seen that the pivotal feed motion of the present invention requires no axial displacement of either the die member or the workpiece along its respective center axis of rotation. However, in certain forming operations, it may be desirable to provide for some axial displacement in combination with the pivotal feed motion of this invention; and this can be accomplished by a shifting of the pivotal axis during or before relative feeding between the die member and the workpiece, such shifting being to a new position offset from, and so no longer exactly coincident with, the common normal to said center axis. The pivotal feed motion which has been just described is continued to a full limit depth of engagement between the die member and the workpiece. It should be understood that FIG. 2 does not represent a necessary starting position for a rolling operation in accordance with this invention, since only a slight separation of the die member and the workpiece are required at the beginning of each cycle.

FIGS. 4 and 5 illustrate further details of relationships and movements between a die member and a workpiece in the practice of the method of the present invention. FIG. 4 illustrates a die member **10** in the form of a crown gear, or near-crown gear, for engaging and forming gear teeth on a workpiece **12**. Such a die member has a pitch cone angle equalling, or approximately equalling, 90°; and it can be shown that during the relative movement of the die member **10** towards the workpiece **12** (indicated by the dashed line positions of die member **10**) the pitch cone angle C for the workpiece remains virtually constant during forming of the workpiece. This results in a final pitch line for the rolling process that is approximately equidistant from the root to the top of the teeth being formed.

In the FIG. 4 view, the center axis of the die member **10** is shown in two relative positions **16** and **16'**. These positions represent a pivotal movement of the die member (about an axis **22**) from a position just at the instant of initial contact with the workpiece **12**, to a full depth position for forming final tooth profile configurations in the workpiece. The portion of the die member **10** which is illustrated is likewise shown in both of these positions, the position shown in dotted lines being representative of final full depth engagement.

The workpiece **12** illustrated in FIG. 4 is a type having an original face cone surface **28** which is smooth and without any tooth slots or initial formations therein prior to rolling engagement with the die member **10**. The face cone surface of the die member, as defined by the top lands **30** of its teeth, is tangent to the face cone surface **28** of the workpiece at the time of initial contact. The ultimate root cone surface **32** of the workpiece is formed by the top land surface of the die member when the die member has reached its limit feed position (represented by the position of center axis **16'**). In a similar fashion, the ultimate top land surface **34** of teeth formed on the workpiece is defined by the common root surface **36** provided in the teeth of the die member **10**. It can be seen that some material of the workpiece is displaced upwardly above the original face cone surface **28** of the blank by the rolling engagement of the die member with the workpiece.

Rotation of the die member and the workpiece about their respective center axes **16** and **18** is started sometime during the initial pivotal feed movement which brings the die member into first contact with the workpiece. Rotation is continued for the duration of the infeed movement, and also, for a period of time after the infeed movement has stopped and has reached its limit position (represented by the pivotal displacement of the die member center axis to 16') to assure that the desired tooth form will be produced around the entire gear.

FIG. 5 illustrates the same relationships shown in FIG. 4, but a different form of die member is illustrated. The die member 10 of FIG. 5 comprises a tapering tool having a pitch cone angle D substantially less than the 90° angle of a crown gear tool. As a result of this decrease in the pitch cone angle of the die member, the pitch cone angle of the workpiece, which changes continually during the rolling process, undergoes a greater change in a direction towards the roots of the teeth being formed. This change in pitch cone angle is depicted in FIG. 5 by the angle formed between the common pitch cone elements 38 and 40, representing, respectively, instantaneous axes of rotation of the die member and the workpiece at the time of initial engagement, and at final full depth engagement. This increased change in pitch cone angle has the very desirable effect of reducing unwanted sliding or scrubbing of material in the root areas of the teeth being formed, and it still permits production of a final tooth profile having a desired tapered depth. Thus, for forming tapered tooth profiles, the method disclosed herein attains a more natural progressive engagement between a die member and a workpiece than has been possible with prior art arrangements using axial feeding of either or both the die member and the workpiece.

FIG. 6 illustrates one embodiment of the shrouding means which may be utilized in the practice of the present invention. In roll-forming processes there is a possibility of unwanted displacement of material in a workpiece, and typically, some form of shrouding means is utilized to prevent a displacing or spilling of material from the ends of the tooth configurations being formed in the workpiece. FIG. 6 illustrates a type of shrouding means which can be mounted on a die member 10 for preventing unwanted displacement of material out of the working zone of a workpiece 12. The illustrated shrouding means includes an internal annular surface 44 which closely conforms to the internal surface formed by the teeth and slots of the die member 10. The internal element 42 is attached to the die member by any suitable means so as to rotate therewith. The shrouding means also includes an external annular member 46 which has an uninterrupted internal surface 48 closely conforming to the outer surface profile of the die member 10. The external element 46 can be fastened directly to the die member, or it can be secured to a portion of a tool support means which carries the die member 10 in a spindle in a gear rolling machine. Exposed surfaces 50 and 52 of the internal and external shroud elements project, by a nominal amount, above the top land surface 30 of the die member. Also, it can be seen that the annular surfaces 44 and 48 of the two shroud elements are conical or spherical in cross section, with their respective radii of curvatures 53A and 53B being taken on centers removed slightly from pivot axis 22 in order to provide necessary clearance as the die member moves into the workpiece.

It will be appreciated that other shrouding means could be used in addition to or in place of that shown, namely, such shrouding means might provide for inner and outer shrouding elements to be mounted in inner and outer positions relative to the workpiece 12. The inner shroud element would be secured to the workpiece 12 to rotate therewith; and the outer shroud element could be secured to a portion of a mounting surface which carries the workpiece in a spindle.

The pivotal feed motion required for the method of this invention can be effected with relatively simple machinery which is able to withstand the very high pressures and forces developed in a cold rolling operation. Essentially, such machinery requires the mounting of the die member and the workpiece so that relative pivotal movement therebetween can be accomplished in accordance with the requirements set forth above. As the die member and workpiece are being brought into engagement, drive means rotates either the die member or the workpiece, or both, about their respective center axes. When only one of the members is rotated, the other will rotate about its axis by the frictional engagement of the two as they are brought together. When both are positively driven, control means may be provided for synchronizing the rotations of each member. Alternative driving arrangements are also possible, e.g., directly driving either the die member or the workpiece, while applying a braking force to the other one of the two.

FIGS. 7 and 8 illustrate, in somewhat schematic form, relatively basic apparatus which may be used for carrying out the method of the present invention. The apparatus which is illustrated is of a type which not only provides for the required pivotal feed motion of this invention, but which also provides for positive rotation of both a die member and a workpiece with means for synchronizing their rotations during a rolling operation.

FIG. 7 shows a machine having a first spindle means 54 for carrying and rotating a die member 10. A second spindle means 56 carries and rotates a workpiece 12. The first and second spindle means are mounted in housings which are positioned relative to one another so that an axis of pivotal movement is maintained at 22 for feeding and withdrawing motions of the die member relative to the workpiece. Suitable means, such as hydraulic ram system (not shown), is provided for effecting a tilting movement of an upper housing carrying the first spindle means 54 relative to a base housing carrying the second spindle means 56.

Since gear rolling requires a rolling engagement of a tool with a work blank, means must be provided for positively driving and rotating either the tool or the blank about its respective axis. In the arrangement shown in FIGS. 7 and 8, driving means, such as motor means connected to the upper spindle 54 by drive shaft 58, are provided for each of the spindles and the die member and the workpiece associated with them. Thus, both of the working elements are driven about their respective center axes for effecting a rolling engagement of the two during a gear forming operation. In order to provide for a timed rotational relationship between the die member and the workpiece, a gear train means is interconnected between the first and second spindle means. The upper spindle means 54 carries a ring gear 60 for rotation therewith, and similarly, the lower spindle means 56 carries a separate ring gear

62 for rotation therewith. As shown in FIG. 8, an upper pinion gear 64 mates with the upper ring gear 60, and the pinion gear 64 is interconnected to a helical change gear 66 carried on a pinion shaft 68 fixed to the the pinion gear. The helical change gear 66 mates with another helical change gear 70 carried on a pinion shaft 72 of a second pinion gear 74. Pinion gear 74 mates with the lower ring gear 62 to complete the gear train. The helical change gears 66 and 70 provide a means for changing relative rotational speeds of the die member and the workpiece. By shifting one or the other of the helical change gears 66 or 70 axially on its associated pinion shaft, a change in ratio can be effected in the rotational speeds of the two spindles 54 and 56 to provide a desired timed rolling relationship of the die member with the workpiece.

As shown in FIG. 8, the center axis of rotation of the upper pinion gear 64 is coincident with the pivot axis about which the die member is fed relative to the workpiece. This allows for a pivotal movement of the housing associated with the upper spindle and the die member, while maintaining a fixed center distance between the pinion shafts 68 and 72. However, it can be appreciated that with this arrangement pivotal movement of the upper spindle relative to the lower spindle results in a moment of angular rotational displacement of the upper ring gear 60; and this rotational displacement is separate and distinct from any rotational moments applied by the driving means associated therewith or by the synchronizing gear train. This moment of rotational movement of the upper spindle, and the die member carried by it, provides a desired component of helical feed that can be controlled to provide for uniform displacement of material on both sides of each tooth being formed, as will be discussed in greater detail later.

FIGS. 9 and 10 illustrate more specific forms of machinery for practicing the present invention from what is shown in the basic arrangements of FIGS. 7 and 8. FIG. 9 is directed primarily to mechanisms associated with pivotal feed movement of a die member 10 relative to a workpiece 12; and FIG. 10 is directed primarily to mechanisms associated with rotating and synchronizing the rotational movement of the die member and the workpiece about their respective center axes.

Referring to FIG. 9, an upper housing 80 of a machine is mounted with a trunnion mounting (not shown in FIG. 9, but indicated at 90 in FIG. 10) that places a trunnion axis on a line which intersects the intersection of the two spindle center axes 16 and 18. Thus, the trunnion axis would be perpendicular to the view shown in FIG. 9 and is indicated as axis 22. This arrangement provides for a pivotal movement of the housing 80 about trunnion axis 22 so as to effect the novel infeed motion required for the practice of the method of this invention. The upper housing 80 contains a first spindle and support structure for the die member 10 in the manner described with reference to FIG. 7 above.

A second housing 79 is carried on a base portion of the machine and is fixed thereto. This housing 79 contains a lower spindle means and support structure which carries the workpiece 12, also as described with reference to FIG. 7 above.

Means for effecting pivotal movement of the upper housing 80 about axis 22 include a hydraulic ram system 81 which drives a fork 82 having two wedge-shaped tines 83 which straddle upper housing 80, being positioned between the latter and two heavy side plates 84 which are rigidly fixed to the machine base. (Only one tine 83 can be seen in FIG. 9, and only the rear side plate 84 is shown, the other being removed for clarity.) The pair of wedge-shaped tines 83 are guided between cooperating pairs of slideways 85 and 86 (only one pair shown). Each slideway 85 is secured to a respective one of said side plates, while the slideways 86 are formed as part of a pair of flange elements 87 (only one shown) which are connected to opposite sides of upper housing 80 by means of pivots 88 (only one shown).

In the orientation illustrated in FIG. 9, when fork 82 is urged to the right by hydraulic ram system 81, the wedge-shaped tines 83 act against immovable slideways 85 to drive flange elements 87 downward and clockwise relative to upper housing 80 about pivots 88, thereby urging upper housing 80 counterclockwise about axis 22. When fork 82 is withdrawn by ram 81, opposing piston means (not shown) act to rotate upper housing 80 clockwise to disengage tool 10 and workpiece 12.

With the arrangement just described, the upper and lower housings of a machine can be adjusted relative to one another through a range of positions which vary the included angle between their axes, permitting the manufacture of gears with a continuum of pitch cone angles. Thus, there is provided basic apparatus for effecting pivotal motion of the type required to satisfy the method of the present invention.

FIG. 10 illustrates details of driving means associated with a gear rolling machine for positively rotating both a die member 10 and a workpiece 12 about their center axes. As with the arrangement described in FIGS. 7 and 8, separate drive motors and drive shafts are provided for rotating an upper spindle means 54 and a lower spindle means 56. These rotations effect a rotation of both the die member 10 and the workpiece 12. The view of FIG. 10 is taken at right angles from the view of FIG. 9, and the trunnion means 90 can be seen in the FIG. 10 view. However, the sliding wedge-shaped tines 83 have been omitted from the FIG. 10 view for the purposes of clarity.

The gear train synchronizing system shown in FIG. 10 functions to provide complete control of the natural helical infeed motion associated with pivotal movement of a die member relative to a workpiece in accordance with this invention. As with the simplified arrangement of FIG. 8, upper and lower pinions 64 and 74 are interconnected by a gear train to adjust relative rates of rotation of a die member relative to a workpiece. An upper spur gear 92 drivingly connects the upper pinion 64 with a lower spur gear 94. The lower spur gear 94 is fixedly mounted on the same shaft 95 as an upper helical gear 66 which, in turn, is drivingly connected to a lower helical gear 70 fixed to the pinion shaft 72 of pinion 74. As with the FIG. 8 arrangement, a sliding adjustment of one helical gear relative to the other provides for a change in turning ratios between the pinion shafts 68 and 72. For this purpose, the upper helical gear 66 is axially slidable on its shaft 95 by a splined hub arrangement. Also, as with the FIG. 8 arrangement, shaft 95, upon which the helical gear 66 and its associated spur gear 94 are mounted, has an axis which is coincident with the pivotal axis 22 about which the upper housing 80 is mounted for movement relative to the lower housing 79.

FIG. 10 illustrates an arrangement for dictating ratio changes to the gear train interposed between the upper and lower rotating spindles of the machine. Basically, the arrangement provides for a lever arm 96 (pivoted at 97 to fixed structure) which can effect sliding movements of the upper helical gear 66 on its hub in accordance with a positioning of the lever 96 by a wedge block 98. The wedge block 98 is, in turn, positioned by a cam means 100 which is shaped to dictate a desired sequence of ratio change for relative rotations between the die member 10 and the workpiece 12 during a forming operation. (However, it should be appreciated that while the relative orientation of lever arm 96, wedge block 98, and cam means 100 to each other is shown properly in FIG. 10, the exact position of these members has been slightly altered in this schematic representation for purposes of clarity and visual simplification.)

FIGS. 11 and 12 illustrate the cam means 100 and wedge block 98 in greater detail. As shown, the wedge follower means 102 is biased by spring 103 (FIG. 10) against wedge block 98, and it functions to impart changes in position of the wedge block to the lever means 96 so as to effect sliding movements of the upper helical gear 66. The wedge block means 98 is similarly biased by spring 99 (FIG. 10) so that it is normally urged downwardly against the surface profile of the cam means 100, and the cam means 100 is keyed to a shaft of the trunnion mounting of the upper housing 80 so that the cam rotates in accordance with the pivotal feed motion of the upper housing and its associated die member. Of course, it will be understood that the cam and lever arrangement just described is only one of many possible means for sliding the helical gear 66, and that this embodiment of the invention can be practiced by using any adjustment means which slides helical gear 66 back and forth through an infinite range of positions on its hub in timed relation to the pivotal feed motion.

The adjustable synchronizing system which has been just described provides for an adjustment in relative feed direction between a die member and a workpiece, as represented in the different feed directions shown in FIGS. 13 through 15. FIG. 13 represents a feed wherein a die member is brought into rolling contact with a workpiece without any additional component of rotation being imparted to the die member relative to the workpiece. FIGS. 14 and 15 illustrate relative feed directions resulting from additional components of rotation being imparted to a die member relative to workpiece so as to control the approach of the die teeth to the workpiece when rolling workpieces having unsymmetrical tooth slots. In each case there is an additional infeed component, which results in a movement which may be considered as being generally helical, and this helical-type movement can be used to facilitate the rolling of gears having unbalanced tooth profiles of the type required for certain tapered tooth formations. This additional component of rotation may be varied as the basic infeed motion of the die member progresses towards the workpiece, and such adjustment can be predetermined by the selection of appropriate cam and wedge shapes for the ratio control system discussed with reference to FIG. 10 above. However, attention is called to the fact that even without an adjustable ratio control system, a natural additional component of rotation is imparted to the die member relative to the workpiece by virtue of its pivoting motion, and this additional component of turning can be controlled and set by selecting certain gear ratios for the bevel gears and spur gears which interconnect the upper spindle means 54 with the lower spindle means 56.

Thus, it can be seen that the pivotal feed motion of the present invention provides for a relatively simple means by which tooth profile can be precisely adjusted in any given motion setup. The basic pivotal feed motion of this invention can be effected with very strong and reliable mechanisms which are relatively simple, and a wide range of adjustment are available.

What is claimed is:

1. A method for roll-forming or roll-finishing tapered gears or the like, comprising the steps of:

feeding a die member and a workpiece relative to each other with a pivotal feed motion about an axis substantially coincident with a common normal to the center axes of rotation of both the die member and the workpiece, and

continuing said feeding step so as to progressively engage the die member and the workpiece with each other to a desired limit depth for rolling and forming gear teeth configurations on said workpiece, said engagement of the die member and the workpiece being accompanied by a step of rotating the die member and the workpiece about their respective axes.

2. The method of claim 1 wherein said step of rotating is effected by drivingly rotating at least one of said die member or said workpiece about its own center axis.

3. The method of claim 1 wherein the center axes of said die member and said workpiece intersect and wherein the axis for said pivotal feed motion passes through the intersection of said center axes.

4. The method of claim 1 wherein the axis for said pivotal feed motion remains stationary throughout progressive engagement of the die member and the workpiece.

5. The method of claim 2 wherein both said die member and said workpiece are drivingly rotated about their respective axes.

6. The method of claim 5 wherein said die member and said workpiece are independently rotated by separate driving torques applied in a predetermined ratio.

7. The method of claim 1 wherein said step of rotating is effected by drivingly rotating one of said die member or said workpiece about its own center axis and by applying a braking force to the other of said die member or said workpiece.

8. The method of claim 1 and including the step of:

varying the rate of feeding said pivotal feed motion relative to a rate of drivingly rotating one of said die member or said workpiece in accordance with a predetermined ratio.

9. The method of claim 1 and including the step of:

controlling the rates of rotation of said die member and said workpiece about their respective center axes relative to each other and in predetermined relation to said pivotal feed motion.

10. A method for roll-forming or roll-finishing tapered gears or the like, comprising the steps of:

feeding a die member and a workpiece relative to each other with a feed motion which is essentially perpendicular, at any given instant, to the instantaneous axis of rotation between the die member and the workpiece, and effecting said feeding step without axial displacement of either the die member or the workpiece along its respective center axis of rotation by moving said die member and said workpiece relative to each other with a pivotal feed motion about an axis substantially coincident with a common normal to the center axes of rotation of both the die member and the workpiece,

continuing said feeding step so as to progressively engage the die member and the workpiece with each other to a desired limit depth for rolling and forming gear teeth configurations on said workpiece, and

rotating the die member and the workpiece about their respective axes at least during engagement of the die member with the workpiece.

11. The method of claim 10 wherein the axis for said pivotal feed motion moves during progressive engagement of the die member and the workpiece.

12. In a machine for roll-forming or roll-finishing tapered gears or the like by rolling together a die member and a workpiece, said machine being of a type which includes a first spindle means for carrying the die member for rotation about its center axis, a second spindle means for carrying the workpiece for rotation about its center axis, and driving means for rotating at least one of said spindles and the die member or workpiece associated therewith, the improvement comprising:

means for relative feeding of the die member and the workpiece into progressive rolling engagement to a desired depth limit by a pivotal feed motion about an axis substantially coincident with a common normal to the center axes of both the die member and the workpiece.

13. The improvement of claim 12 wherein said die member and said workpiece are positioned in said machine so that their center axes intersect, and wherein the axis for said pivotal feed motion passes through the intersection of said center axes.

14. The improvement of claim 12 wherein said first spindle means is mounted for said pivotal feed motion relative to a fixed position of said second spindle means.

15. The improvement of claim 12 further comprising means for controlling the rate of rotation of said die member about its center axis relative to the rate of rotation of said workpiece about its center axis.

16. The improvement of claim 15 wherein said controlling means is a gear train interconnecting said first and second spindle means.

17. The improvement of claim 15 wherein said controlling includes means for varying said relative rates of rotation during said progressive rolling engagement.

18. The improvement of claim 17 wherein said varying means is responsive to said pivotal feed motion.

19. In a machine for roll-forming or roll-finishing tapered gears or the like by rolling together a die member and a workpiece, said machine being of a type which includes a first spindle means for carrying the die member for rotation about its center axis, a second spindle means for carrying the workpiece for rotation about its center axis, and driving means for rotating at least one of said spindles and the die member or workpiece associated therewith, the improvement comprising:

means for mounting said first spindle for angular pivotal movement about an axis substantially coincident with a common normal to the center axes of both the die member and the workpiece, and

means for moving said first spindle about its pivot axis to pivotally feed a die member and a workpiece relative to each other without axial displacement of either the die member or the workpiece along its respective center axis of rotation, said pivotal feed motion being essentially perpendicular, at any given instant, to the instantaneous axis of rotation between the die member and the workpiece.

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